International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 3, Jun 2018, 659-666

OPTIMIZATION OF PROCESS PARAMETERS DURING TIG WELDING OF Si-Mg-Mn AL ALLOY 64430

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ABSTRACT

The experimental investigation has been carried out to study the influence of welding current, shield gas flow rate and filler rod on ultimate tensile strength, ultimate load, yield load and yield stress of commercially available Al alloy 64430. The Taguchi method L9 is used to analyze the TIG welding parameters for maximizing the mechanical properties. By using Taguchi and Analysis of variance technique find the effect of individual factors which provides optimal results under varying conditions.

KEYWORDS: Al Alloy 64430, Tungsten Inert Gas, Taguchi, ANOVA, Ultimate Tensile Strength & Yield Stress

Received: Apr 18, 2018**; Accepted**: May 08, 2018; **Published:** May 28, 2018; **Paper Id.:** IJMPERDJUN201871

Original Article

INTRODUCTION

Unique properties of aluminum and aluminum alloy such as thermal and electrical conductivity, corrosion resistance, workability and ease of joining have made it as most desirable material to use in versatile ways. In specific, Al alloy 64430 has high corrosion resistance, excellent extrudability which paved the way to widespread used in aerospace, automobile and shipbuilding industries [1].The key technology in the mass production of structural components is welding. Comparatively with easier acceptability and better economy, Tungsten inert gas welding (TIG) is a preferred welding process for Al alloy 64430 [2]. Tungsten inert gas welding is an arc welding process the metals are joined by heating them with an arc between an consumes able tungsten electrode and the metal. The TIG welding process is applicable for welding of these alloys and some parameters as constant and others are variable are maintained. The TIG welding process relates to AC power supply as compared to DC power supply because aluminum melts at low temperature. The DC power supply prefers 20% energy where as AC power supply the average of the energy output both the terminal are to be same. The process involves melting the work piece and the filler rod by using the formation of gases. Argon is used as shielding gas because both are not chemically react. The gases used for better welding. The inert gas, preventing oxidation and transfer heat from the electrode to metal which helps to start and keep in a constant arc. The TIG welding parameter like welding current, welding voltage, gas flow are considered which affect the tensile strength of the Al alloy joint. Filler wire is continuously filling into the weld pool for better welding process. Tensile strength is mainly affected by the welding parameter.

The parameters that influence the welding strength are welding current, gas flow rate, welding speed, arc voltage, type of filler rod and polarity of weld etc. The quality of weld mostly dependent on the process condition and the mechanical properties are however influenced by the temperature generated during the welding process [3]. Also, the metallurgical transformation of material close to the weld joint has great influence [4]. As an alloy of Al 6XXX series is more sensitive to hot cracking, the filler rod selection is very crucial for promoting fluidity in aluminum [5].

The research established by Adalarasan et al [6] to optimize welding parameters such as welding current, voltage, polarity of weld for AA 6061 aluminum alloy. They have concluded that the process current and gas flow rate have a significant effect on the quality of weld. The influence of welding parameters and heat affected zone of aluminum structures have been studied by [7] to optimize the welding parameters. It was established that increased temperature and reduced cooling rate has influence to obtain heat affected zone. Experimental and numerical investigations carried out [8] on AA 7075 aluminum alloy showed that the operating parameters, such as welding current and gas flow rate has a significant effect on the quality of weld and mechanical properties. Experimental investigation to find the effect of arc voltage, welding current and welding speed on the mechanical properties of the joint has been carried out [9] on AA 6061 revealed that as the heat input increases, the fatigue life decreases. However, it was also found that impact energy initially increased and then decreased. The strength of weld differs as it depends upon the welding process used. By varying the input process parameters combination the output would be different welded joints with significant variation in their mechanical properties. Kumar and Sundar Rajan [10] used Taguchi method to optimize the pulsed TIG welding process parameters of heat-treatable (Al-Mg-Si) aluminum alloy weldment for maximizing the mechanical properties. Kishore et al. [11] analyzed the effect of process parameters for welding of AA6351 using TIG welding. Several control factors were found to predominant influence weld quality. The % contributions from each parameter were computed through which optimal parameters were identified. ANOVA method was used to checking the adequacy of data obtained. The experiment revealed that low current values have created a lack of penetration and high travel speed has caused lack of fusion in welding AA6351.

The aim of the present work is to investigate the effect of welding current, shield gas flow rate and filler rod on ultimate tensile strength and yield stress of commercially available Al alloy 64430.

EXPERIMENTAL SET-UP

Specimen Material

The material under investigation is a flat plate of commercial Al alloy 64430 and the chemical analysis of the test specimen is presented in Table 1 and thermo mechanical properties are shown in Table 2.

Table 1: Chemical Analysis

S. No.	Cu (%)	Mg (%)	Si (%)	Fe (%)	Mn (%)	Zn (%)	Cr (%)	Ti (%)	Al (%)
Al alloy 64430	0.019	0.828	0.829	0.257	0.566	0.026	0.028	0.030	97.417
AA 4043 filler rod	0.3	0.05	5.0	0.08	0.05	0.1	-	0.2	94.22

Table 2: Thermo-Mechanical Properties

S. No.	1	2	3	4	5	6	7
Property	Density /(kg·cm^{-3})	Melting point /°C	Modulus of elasticity /GPa	Thermal conductivity /(W·m^{-1}·K^{-1})	Tensile strength (min.) /MPa	Proof stress (min.) /MPa	Elongation (A50 mm) /%
Value	2710	555	70	180	310	255	7

TIG Welding Machine

The experimental setup consists of a TIG welding machine; Best weld TIG which has an input voltage of 380V. The specifications of the machine are presented in Table 3. Aluminum alloy poses defects such as porosity, distortion, solidification and shrinkage when fusion welding is adapted. Moreover, lengthy butt and lap joints of aluminum alloys are difficult to be done without distortion using conventional techniques. When aluminum alloys are subjected to post weld solutionizing and aging, mechanical properties can be enhanced further, which leads to development and adoption of TIG welding.

Table 3: Specifications of TIG Welding Machine

S. No.	Parameter	Specification
1	Model	TIG 400 AC/DC
2	Input voltage	380 AC ± 15%
3	Phase	3
4	Frequency	50/60 Hz
5	Input current	14A
6	Welding current range	5-400 A

Selection of Process Parameters

Tungsten Inert Gas Welding is a multi-factor metal fabrication technique. The Various process parameters, effects of the weld bead geometry, weldment quality and also on mechanical and metallurgical properties of the weldment include welding current, welding voltage, gas flow rate, electrode diameter, nozzle gap, etc. To find out optimal process conditions through a limited number of experimental runs are undertaking in this study to use three levels of conventional process parameters viz. Welding current, gas flow rate and filler rod diameter. Output parameters considered are ultimate load, ultimate tensile strength, elongation, yield load and yield stress. Based on the literature, 3 levels of input parameters are chosen and Taguchi based technique has been adapted for combinations of operating parameters to form a L9 orthogonal array. Input parameters and their levels are presented in Table 4 and design of experiments for L9 orthogonal array is presented in Table 5.

Table 4: Parameters and their Levels

Parameter	Level 1	Level 2	Level 3
Current (A)	250	300	350
Gas flow rate (KN/mm^2)	10	15	20
Filler rod diameter(mm)	1	2	3

Table 5: Design of Experiments

Trail	Current (A)	Gas Flow Rate (KN/mm^2)	Filler Rod Diameter (mm)
1	250	10	1
2	250	15	2
3	250	20	3

Table 5: Contd.,

4	300	10	2
5	300	15	3
6	300	20	1
7	350	10	3
8	350	15	1
9	350	20	2

Specimen Preparation

Based on Table 5, butt joints were made using gas tungsten arc welding (GTAW) process. Three different welding current in the steps of 250 A, 300 A & 350 A have been used. The filler rod of AA 4043 of various diameters like Ø1mm, Ø 2mm & Ø 3mm and argon is used as shielding gas with gas flow rate of 10 KN/mm^2, 15 $KN/mm^2$and 20 KN/mm^2 have been used in preparing the welded specimens. Prior to welding, the base metal sheets were pickled with a solution of NaOH and HNO_3, wire brushed, and decreased using acetone. The sheets to be welded by maintaining various parameters and were put on a steel backing bar and the ends were clamped for managing the alignment and gap. The weld joint is completed in a single pass. Standard operating procedures have been followed in preparing 9 specimens (size: 250 mm X 30 mm X 5 mm) and the welded specimens are shown in Figure 1.

Figure 1: Tensile Testing has been Carried Out on Weld Specimens using UTM Capacity of 300 KN based on the ASTM B557: 2006 Standard

Testing of Welded Specimens

ASTM B557: 2006 standard has been adapted to test the specimens [12]. Tensile tests have been carried out by Universal Testing Machine. All the welded specimens were failed in the weld region. Tensile testing has been carried out on welded specimen using UTM based on the ASTM B557: 2006.

The ultimate tensile strength of the weld joint is the strength of the weld.

RESULTS AND DISCUSSIONS

Out of the tests conducted, the output parameters investigated are ultimate tensile strength, percentage of elongation and yield stress. The exhaustive results of the present investigation are presented in Table 6.

Table 6: Test Results

Sample No.	Input Parameters			Responses		
	Current	Gas Flow Rate (KN/mm^2)	Filler Rod Dia. (mm)	Ultimate Tensile Strength (N/mm^2)	Elongation (%)	Yield Stress (N/mm^2)
1	250	10	1	115.400	2.460	72.328
2	250	15	2	134.137	2.860	112.450
3	250	20	3	115.114	2.720	111.801
4	300	10	2	127.573	3.060	123.089
5	300	15	3	138.906	2.620	86.458
6	300	20	1	112.096	2.540	73.769
7	350	10	3	129.774	3.860	129.774
8	350	15	1	114.876	1.840	114.876
9	350	20	2	114.164	1.720	112.891

Tensile Test

Interaction effects of welding current and inert gas flow rate on ultimate tensile strength (UTS) are shown in Figure 2. The results reveal that for various inert gas flow rates, the increase in welding current initially increases the tensile strength, reaches a maximum value and then decrease. The increase in welding current improves the metal penetration during the TIG welding process, thereby improves weld properties. The lower value of current resulted in a reduced fusion zone leads to poor joint strength. The higher and lower welding current lead to poor bonding due to high heat generation and low heat generation respectively. The optimum heat generation creates a quality weld. The result also shows that a moderate level of shielding gas flow rate (15 KN/mm^2) and filler rod diameter of 3 mm is necessary for better strength of joints. A lower level of gas flow rate cannot be recommended to produce a better response. The maximum ultimate strength of the joint fabricated by TIG welding experimental runs is 138.906 MPa.

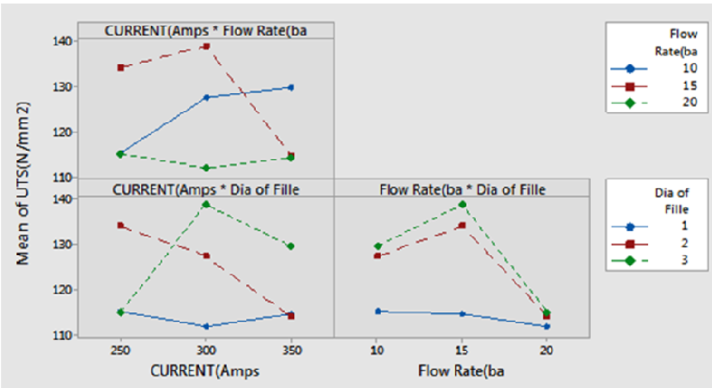

Figure 2: Interaction Effects of Welding Current and Inert Gas Flow Rate on Ultimate Tensile Strength

ANOVA

Analysis of Variance (ANOVA) is a mathematical technique which breaks total variation down into accountable sources. Sum of squares is calculated by the magnitude of each error value can be squared to provide a measurement of the total variation present. Error variance, usually termed just variance, is equal to the sum of squares of error divided by the degree of freedom of error. Error variance is a measure of the variation due to all the uncontrolled parameters, including measurement error involved in a particular experiment. The DOE and ANOVA table were calculated by MINITAB version 11.

The F-test is simply a ratio of sample variances as shown in below equation. When this ratio becomes large enough, the two sample variances are accepted as being unequal at some confidence level. To determine whether an F ratio of two sample variances is statistically large enough, three pieces of information are considered. These are the confidence level, degree of freedom associated with the sample variance in the numerator and the degree of freedom associated with the sample variance in the denominator. F-test values are found from the F-test table.The S/N ratio for welded specimens is shown in Table 7 and ANOVA table for ultimate tensile strength is presented in Table 8 whereas, response table for ultimate tensile strength is presented in Table 9.

Table 7: S/N Ratio

Specimen No.	S/N Ratio
1	36.9166
2	37.6693
3	37.2019
4	35.8960
5	36.7916
6	36.6895
7	36.9034
8	38.1643
9	37.5540

Table 8: ANOVA Table for Ultimate Tensile Strength

Source	DF	Sum of Square	Mean Square	F - Value	Probability
Current (A)	2	129.05	64.527	8.12	0.110
Gas flow rate (bar)	2	99.40	49.699	6.25	0.138
Filler rod dia. (mm)	2	11.29	5.643	0.71	0.485
Error	2	15.89	7.946		
Total	**8**	**255.63**			

Table 9: Response Table for Ultimate Tensile Strength

Level	Current (A)	Gas Flow Rate (bar)	Filler Rod Dia. (mm)
1	121.6	124.2	114.1
2	126.2	129.3	125.3
3	119.6	113.8	127.9
Delta	6.6	15.5	13.8
Rank	3	1	2

From the ANOVA table F test value is very significant. The analysis of variance was accomplished for a 95% confidence level. In this we make an acceptance that value of P <0.5 are found to be an important parameter. Due to the variation of the parameters the optimum welding condition is taken into account the TAGUCHI method is designed to analyze a single performance characteristic. The performance analysis of multiple characteristics is much more complicated than the single performance characteristic. The main effects plot of ultimate tensile strength is presented in Figure 3.

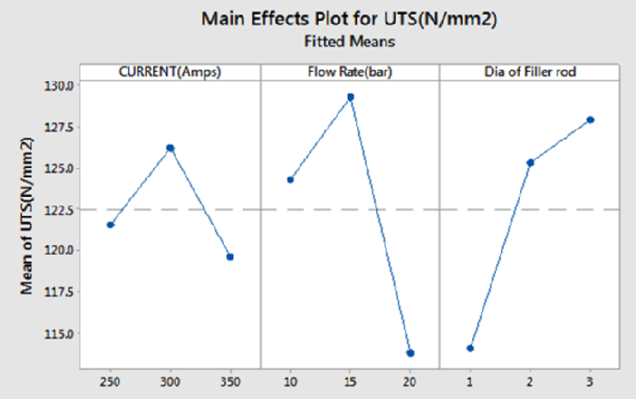

Figure 3: Main Effect Plot of Ultimate Tensile Strength

The taguchi experimental design was successfully conducted for maximize weld strength of aluminum alloy specimen of TIG welding parameters. In this study Taguchi orthogonal array, signal to noise ratio, analysis of variance were used to optimize the welding parameters.

CONCLUSIONS

All the experimental runs are analyzed by safely measured in order to maintain the low error factor and to determine the result to produce the efficient weld joint with the Al alloy specimen. The following conclusions are considered from the collected data by investigating the input and output parameter.

- Maximum tensile strength of 138.906 MPa is obtained at welding current of 300 A, gas flow rate of 15 bar and filler rod diameter of 3 mm.
- The tensile strength of weld joint of Al alloy increases with increase in welding current 300AMP for gas flow rate of 15 bars and after that tensile strength decreases by again increasing welding current.
- The gas flow rate 15 bar affects the maximum tensile strength.

From this we conclude that the gas flow rate required, preventing the oxidation and shielding, but more flow could be detrimental as could cause cooling.

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